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CONFORMAL THERMOSTATING OF HIGH-PRESSURE DIE CASTINGS WITH THE INCREASED TIGHTNESS

TERMOSTATOWANIE KONFORMALNE WYSOKOCIŚNIENIOWYCH ODLEWÓW O PODWYŻSZONEJ SZCZELNOŚCI

***Summary**: In the paper, the exemplary concept, together with the analysis of the obtained results from the experimental trials of thermostating using the conformal system in the cold-chamber high-pressure die casting process of aluminium alloy, was described. Construction of the experimental system of thermostating channels, mapping the surface of the cavity, as being placed in the core, shaping the internal geometry of casting with a required increased tightness was performed. The results of the numerical simulations for a given case and the results of the experiments and RTG examinations of the castings made on a real system, utilizing the designed cores, performed in increment technology from steel 1.2709 were submitted.*

***Keywords**: HPDC, aluminium alloys, thermostating, conformal systems, RTG examinations*

***Streszczenie**: W pracy przedstawiono przykładową koncepcję wraz z analizą otrzymanych wyników z prób eksperymentalnych dla konformalnego układu termostatowania odlewniczej formy wysokociśnieniowej do odlewania zimno-komorowego stopów aluminium. Dokonano konstrukcji doświadczalnego układu kanałów termostatujących odwzorowujących powierzchnię wnęki formy, umieszczonych w rdzeniu kształtującym wewnętrzną geometrię odlewu o wymaganej podwyższonej szczelności, przedstawiono wyniki symulacji numerycznych dla zadanego przypadku oraz wyniki doświadczeń oraz badań RTG odlewów wykonanych na rzeczywistym układzie wykorzystującym zaprojektowane rdzenie wykonane w technologii przyrostowej z stali 1.2709.*

***Słowa kluczowe**: HPDC, stopy aluminium, termostatowanie, układy konformalne, badania RTG*

The assumptions of conformal thermostating

In technology of manufacturing the high-pressure castings from light-metal alloys, each element of technological process is important from the viewpoint of quality and repeatability of production; however, the process of thermostating of pressure form,the related equipment and the system of channels in form seems to be dominating. The conditions for cooling down of metal in mold affect not only the physical properties, quality and aesthetics but first of all, the price of final product what is significant for the profitability of production and profits of the company. In the time of absolute struggle for maintaining the profitability of production, each new technology, causing the abbreviation of time of production of the elements from aluminium or zinc alloys, with the preservation of the assumed quality is invaluable and very quickly finds the application in a wide group of producers. When observing the development of machines and thermostating technologies of tools, we may see that it goes in two directions: extreme abbreviation of the time of cooling down and obtaining of new properties of high-pressure castings *via* aware and controllable creation of the appropriate surface of temperature in the particular parts of the pressure mold so as it could have a local effect on the structure (directional crystallisation).

Methods of conformal thermostating of casting tools

The method of thermostating of pressure molds and the employed fittings and equipment are linked with the type of casted alloy, parameters of alloy (temperature of liquid, degree of degassing), size of the formed element and the number of mold cavities (which is connected with the size of a tool and system of thermostating) and the requirements set for the final product. In the case of castings from aluminium alloys, the pressure mold should be heated up even to temperature of ca. 200°C. The successive criterion is connected with the requirements set for the final product and concerns the dimensions and their tolerance, repeatability of a cycle, shape deformation and high quality of the product's surface. All the mentioned factors determine the project and performance of the tools such as the injection mold and choice of the equipment for its thermostating. The system of thermostating of the mold includes the following elements and subunits:

- system of thermostating of pressure mold (cooling channels are performed within the mold),
- the external cooling equipment, supplying the cooling medium to pressure mold.

The task of thermostating devices is to prepare appropriately the thermostating liquid (heating up to the required temperature), and then, to transport it via pressure channels to the pressure mold, where, using the cooling channels' systems, the exchange of heat between the mold heated by liquid metal and cooling liquid is carried out. The effectiveness of heat exchange is determined by the size of mold (its thermal capacity), difference of temperature between mold and liquid metal, material of the mold (heat conductivity), construction of the thermostating system (distribution of channels, their cross-section and length), the type of the employed thermostating medium and performance of the thermostating equipment.

The system of channels by which the thermostating medium flows is especially important element of pressure die casting molds. The mentioned channels should be placed possibly near surface and their system should ensure rapid heat exchange. Their cross-section should be found between 8–14 mm [1]; it is dependent, *inter alia*, on the distance from the neighbouring channels and the size of mold and by this, the quantity of the heat necessary for its removal from mold during the technological process.

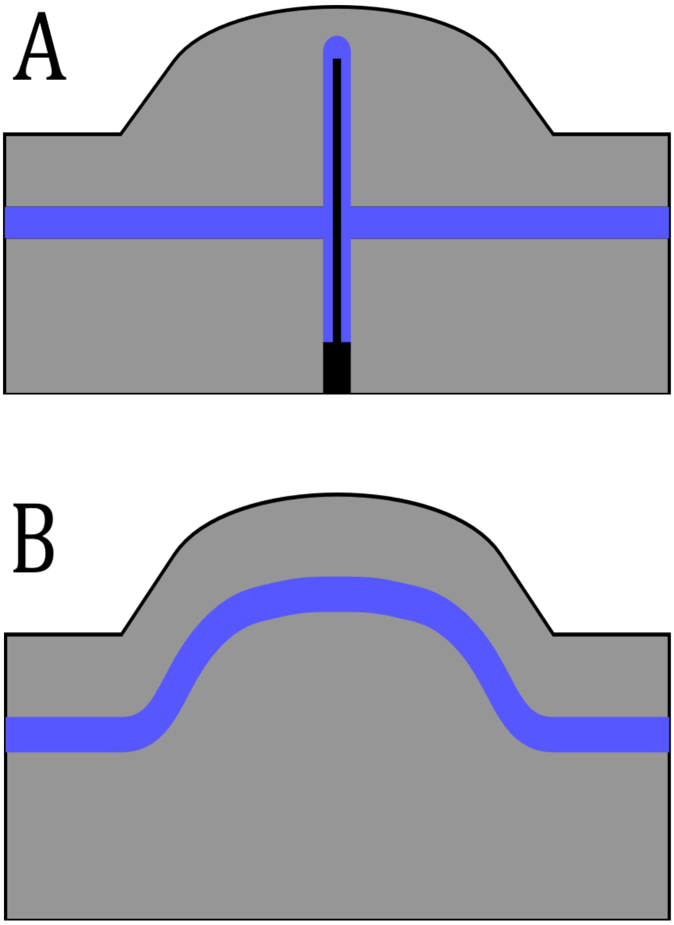

Fig. 1. Traditional thermostating channels with the application of baffle (A) and conformal channels, produced in additive technology (B)

There are many constructional solutions of pressure die cat molds where the shape of cavity (cavities), the system of ejectors or other functional elements of mold disables the correct running of cooling channels. In such cases, the elements of molds, cavities (inserts) or parts (cores) are produced with the application of the so-called additive technologies, facilitating performance of thermostating channels in any cross-section and in any shape.

The additive technology methods originate from the methods of rapid prototyping (RP) where it consists in a quick production of very complicated shapes of elements with a big precision, at a very short time. At present, the time for introduction of new projects for long-run production of pressure die castings is very short and the limitations are caused only by the technologies of producing the prototypes and tools. When striving at the abbreviation of the mentioned time, the constant development of Rapid Tooling (RT) methods is something like a natural consequence of the quick prototyping. The application and development of the discussed methods allows a rapid and flexible answer to the needs and requirements of the customers (change in the shape of tools) and moreover, it allows obtaining the measurable profits, resulting from the abbreviation of production time and reduction of costs. The additive methods of tool production are one of RT varieties [2], [3]. One of the applications includes production of inserts/cores of pressure molds with any system of thermostating channels is respect of their cross-section and run inside the molds. It gives the unlimited possibilities in designing and production of cooling systems adjusted to the shape of the generated casting, giving simultaneously, in certain cases, the abbreviation of the time of its cooling and by this, the cycle time by even 20% [4].

The complete time of the process of the high-pressure die casting is mostly dependent on the length of the stage of cooling down the casting in the mold. The mentioned time is necessary for obtaining (by the liquid metal, crystallizing in the mold) of the sufficient temperature, enabling its safe removal without the change in geometry and the structure, which guarantees obtaining the assumed strength and utility properties. The effective cooling of the pressure mold is very important as it affects not only the time of the cycle but also the quality of the produced castings [5]. The traditional cooling channels are usually performed as simple opening, drilled in a bloc of the mold what causes geometric limitations of their shape and run and by this, in the flow of cooling liquid and heat receipt in the particular areas. In the present paper, the example of the modern method for production of pressure molds, with the application of the s-called additive technologies of direct melting of metal powders with laser application, has been submitted.

The research problem

The particular case of the pressure die castings, requiring the application of conformal thermostating systems refers to the castings for the products requiring the increased tightness. The assumption of the conducted research provided the improvement of the process and rise of the quality of the high pressure die castings, constituting the casted element of mechanism dealing with the liquid under increased pressure. Casting of the mentioned type must be characterized by the provided repeatable low number of casting defects in mass production, occurring at internal surface which has a direct contact with the liquid in the targeted (final) product. Defects, the elimination of which is indispensable for ensuring the repeatable quality of the product include, first of all, gas porosity and shrinkage porosity which may affect the tightness of the product.

The assumed goal of the conducted operations provided moving away the porosities generated in the casting as far as possible from the external walls of its geometry and forcing the fragmentation of microstructure of casting grains, causing the strengthening of resistance in critical zone from the viewpoint of product's functionality. Fig. 2. represents the exit system of the cores' thermostating, as fixed in the cavities of the high-pressure mold; the internal geometry of the castings as shaped by the mold cores, is a zone requiring the increased tightness, being sealed in the final product and being endangered to direct and continuous contact with the liquid.

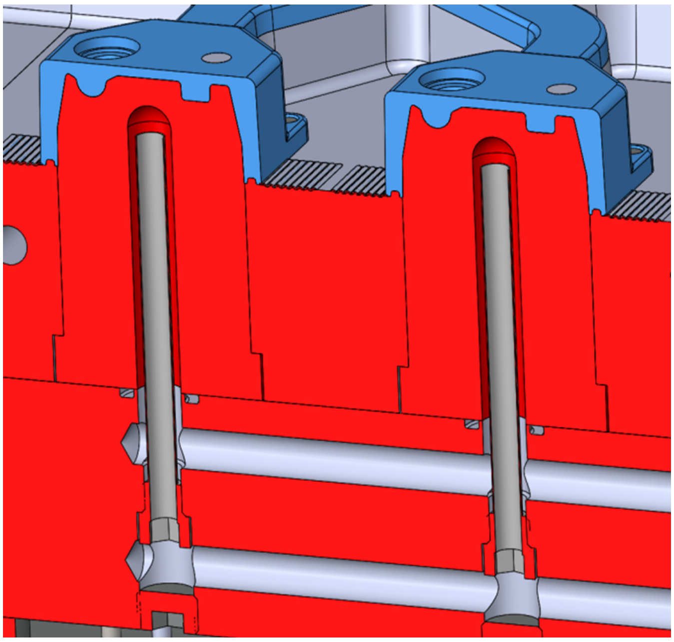

Fig. 2. Traditional system of thermostating applied to the cores of mold; at the cross--section of two cavities of the mold, there were marked the castings together with the gating system (blue colour)

The boundary condition of the implemented research included the application of the existing four-cavity casting mold intended for the high-pressure die casting of silumins. Each cavity of the mold was equipped with the exchangeable molding core, mapping the internal geometry of the casting.

In the original system, the mold used a traditional system of thermostating the cores, performed in a form of holes, drilled in the mold cores, equipped with the Meusburger nozzles E211196 [6] supplying the thermostating medium in the core's axis. The adopted assumption provided a lack of the change in process parameters excluding the time of coagulation and cooling of the castings. The casting process for a given mold was implemented in cold-chamber high-pressure die casting machine Frech K510. Fig. 3 illustrates a movable part of the mold, employed in the conducted experiments, in 3D graphical form generated from CAD documentation.

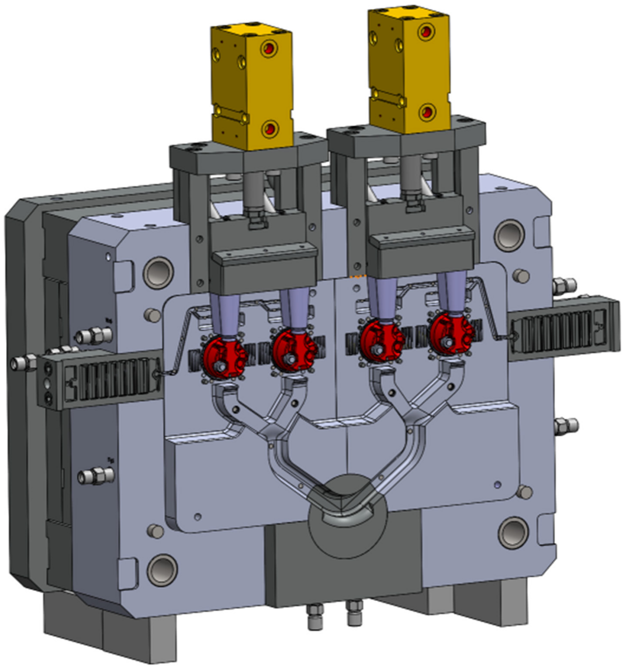

Fig. 3. 3D model of a movable part of the HPDC die casting mold, employed in the studies; cores have been marked by red colour

Methodology of the experiment

The adopted assumption of the method of improving the quality of the casting consisted in the application of the conformal system of thermostating in the mold-shaping cores. On the grounds of the earlier developed solution and elaborations [7], the concept of the system of channels, capable to be placed inside the geometry of shaping core was developed, assuming also lack of modification of its external geometry and connection of thermostating liquid system.

It was also adopted that the core with the conformal channels was performed in accordance with the earlier developed and verified [7] method, using print technology 3D SLM from the steel with the commercial mark "MS1", being the equivalent of hot work tool steel, with marking 1.2709.

The system of channels was designed to achieve the possibly highest length and most effective conformal mapping of external surfaces of molding core, distanded by 3 mm. In the case of horizontal planes, there was undertaken the decision about introducing the complicated geometry of the channel so as to fill the available space as much as possible, with the simultaneous preservation of minimal distances between the channels, being equal to 3 mm.

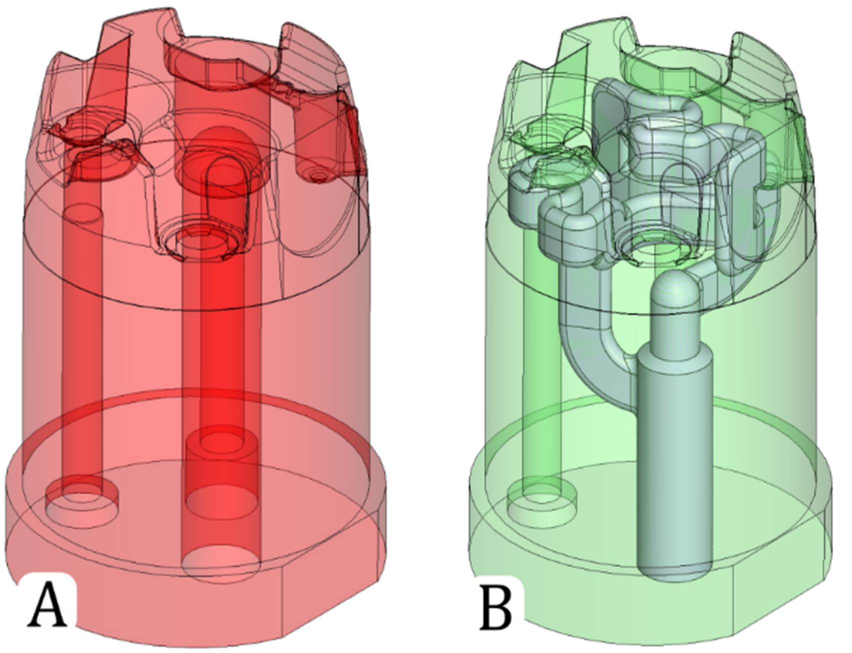

Fig. 4. Model 3D CAD in half-transparency of the core with the traditional thermostating system, with the space for single nozzle in the hole in the middle (A) and core with the conformal thermostating system (B)

The conducted experiments included production of the castings in the mold, equipped with cores with the traditional cooling system as well as conformal cores, with the possible minimization of the number of the introduced process variables. The temperature of the liquid in thermostating system amounted to 60°C. The oil was used as medium. The traditional system of thermostating of molding inserts also employed oil as medium. Thermostating was ensured owing to equipment Robamat Thermocast 5212, integrated with the casting station. In order to eliminate the porosity as much as possible, casting with the application of vacuum, ensured by Fondarex device, connected to cavities of the mold via the geometry of cooling vents, was employed.

The the casting machine ran in automatic cycle; the castings together with the gating system were removed from the cavity of the mold, using the industrial robot, and were, in automatic cycle, placed in bath with ambient water to be cooled down; then, they were placed on the press, where the residues of gating system and burrs were automatically removed.

The developed cores were produced in 3D printing technology, and then, subjected to heat treatment and finishing treatment with the aim to obtain the appropriate mapping of the expected geometry and the appropriately low roughness of the top layer, facilitating their correct assembling and work in the die casting mold.

A series of the trials was carried out in foundry equipment. The nearly eutectic alloy of aluminium EN AC-44300 acc. to PN-EN 1706 was employed. The choice of casting material was dictated by the requirements of the Customer, ordering the production of the castings. The temperature of material in heating furnace of the casting machine was equal to 750°C.

During the studies, the manufacturing series of die castings from the mold equipped with traditional cores as well as the cores with the conformal channels were performed. The castings produced during the first 20 start-up cycles of machines during the mass production were discarded due to lack of the full thermal stabilisation of casting tool. From among the castings performed after start-up, the samples were collected for the needs of the tests of their properties.

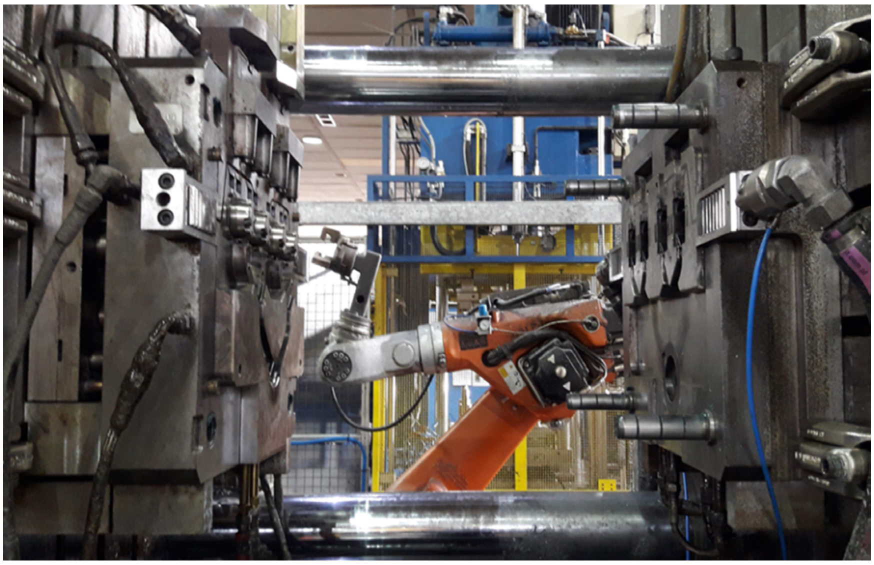

Fig. 5. Casting mold equipped in cores with conformal thermostating system, assembled on casting machine Frech K510

The results of the conducted studies

As early as at the design stage, in order to verify the potential effectiveness of the considered system, a series of numerical simulations for a set casting process with the support of ProCAST software [8] was carried out. One of the verified aspects included the distribution of temperatures inside the core during its work in a casting mold what allowed stating that the developed cores would not be endangered to decrease of the strength, caused too high working temperature. Verification embraced different temperature parameters of thermostating system for the cycle including the cores. Fig. 6 shows the exemplary result of simulation for temperature of 70°C, being the upper value, reachable by thermostating device, at the planned setting up of 60°C. It is

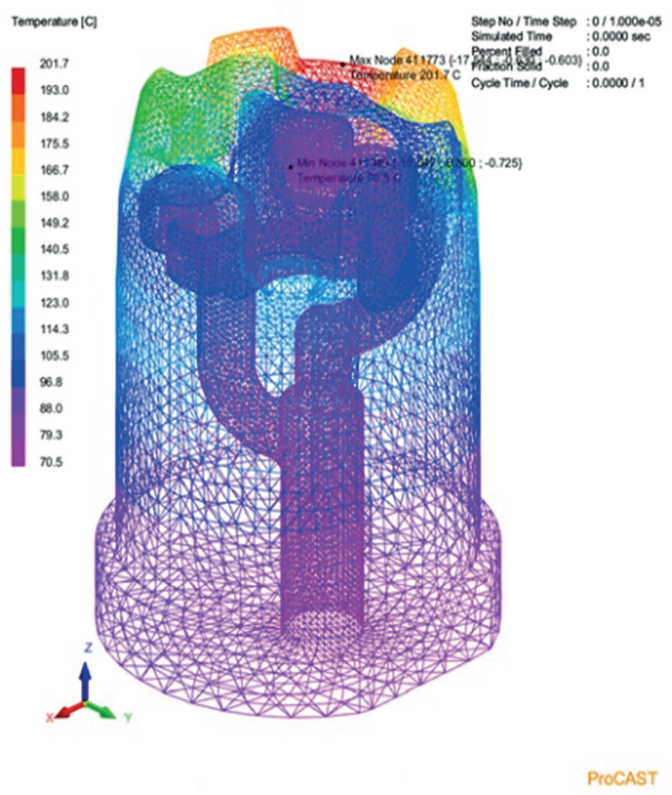

Fig. 6. Distribution of temperatures in the core with the conformal channels for the set temperature of liquid, equal to 70°C

visible that the maximum temperature of the core reached 201.7°C what was recognized as a safe value for the structure of steel from which the cores were produced.

The performed castings were verified in respect of porosity, using X-Ray examination; mechanical properties were checked by the tests of hardness and tightness. The dimensional properties were tested as well. Any changes in dimension deviations, resulting from the casting process were not found.

X-Ray images, in the quantity of 12 pcs from each casting, coming from the both types of the cores were analysed in respect of possible tightness defects of the casting process. The greatest participation of porosity was observed in the site directly at the filling gate. In the case of the castings with the application of the cores with conformal system, it was found that the larger porosity areas were separated; the single pores had smaller volume and did not have the tendency to mutual linking. Any direct decrease of the porosity volume was not observed but the obtained result may positively affect the key aspect of the final product, the tightness, which mainly depends on the obtained castings. Fig. 7. represents the photographs of the exemplary castings, selected from among the tested samples due to the greatest participation of the revealed porosity. A zone at the filling gate was marked in the photos. For comparison, the X-ray image of the casting with the application of the conformal system of thermostating shows the product after machining, considering, *inter alia*, after-drilling of the hole, placed directly in a critical zone of porosity.

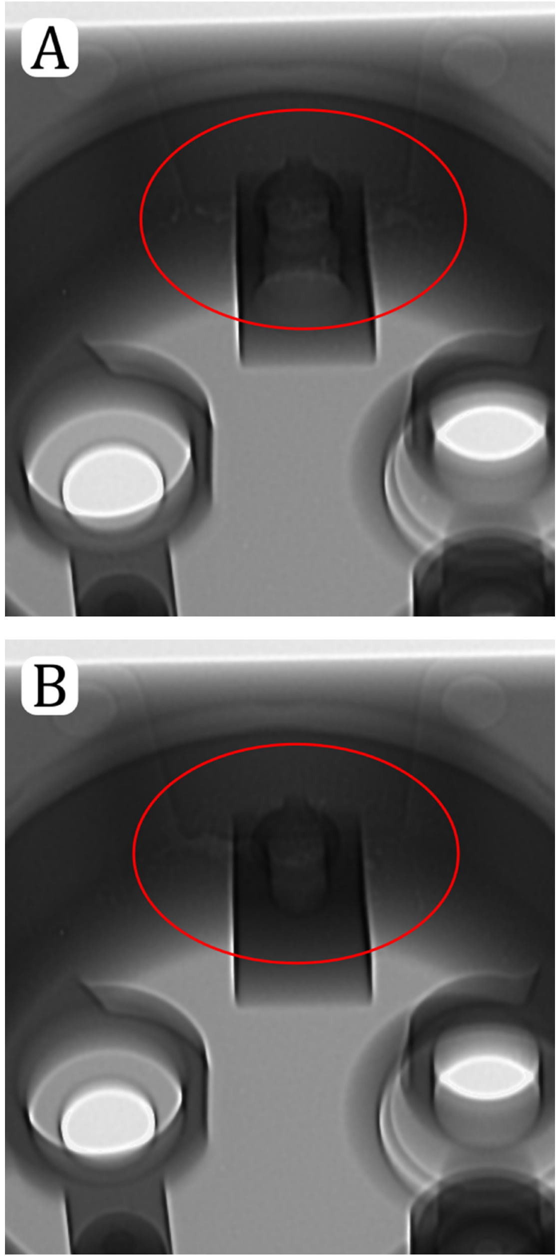

Fig. 7. X-Ray image with filter, highlighting the defects (Bosello HDI) of the casting, with the application of the core with conformal system (A) casting after the operation of after-drilling of the whole in the marked zone, the core with the traditional system (B); red outline means the zone with the observed highest participation of porosity, situated directly at the filling gate

Discussion of the results and conclusions

On the grounds of the obtained results, it was stated that the application of conformal system of thermostating the cores affected positively the quality of the obtained castings and the process parameters, potentially having also the effect on the prolongation of the tool's durability.

From the tightness viewpoint, the castings, obtained from the mold equipped with the experimental thermostating system were characterized by a better distribution of porosity which was shifted from the critical zone and disintegrated. There was observed a lack of the effect of thermostating on dimensional properties what is a crucial property from the point of view of designing the casting molds. On the stage of construction, the correct anticipation of casting shrinkage is indispensable.

The results of the experiments indicate that in the case of the castings where the application of the traditional thermostating system which would well map the geometry of the casting is impossible, the performance of molding elements or their parts such as cores in technology of print 3D, with the consideration of conformal channels may be recommended.

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